A STUDY OF ACCIDENT MECHANISMS ON AN URBAN MOTORWAY

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INTRODUCTION

The Ayalon Highway is a unique motorway in Israel. It crosses the Tel-Aviv metropolis from north to south and connects two main motorways, leading to Haifa and Jerusalem. It carries one of the highest traffic volumes throughout the country -- about 100,000 vehicles daily. Having eight interchanges on about thirteen kilometers of motorway, Ayalon Highway serves as a fast access to any district (industrial zone, business centres, residential areas, university facilities) of greater Tel Aviv. Being heavily travelled most hours of the day, Ayalon Highway is deemed to satisfy a high standard of safety, especially concerning road conditions and traffic arrangements.

In 1996, the Ayalon Highway Authority began applying some tools -- bollards (Hakkert & Gitelman, 1997), which are believed to improve the traffic arrangement at motorway exits. In order to evaluate the potential effect of this treatment and to highlight the needs for other remedial measures, a detailed analysis of accidents occurring on the Ayalon motorway was necessitated.

As had happened with many other accident studies, the data attainable from the Central Bureau of Statistics were unsatisfactory for the study purposes. Except for the date, hour, road number, collision type, number of vehicles involved, and number of injuries, neither the exact location nor the events and manoeuvres prior to the collision could be reconstructed using these data. Hence, in order to supplement the lack of information, we were forced to apply to initial police files. As underlined in Gitelman & Hakkert (1996), it is a widespread phenomenon that a detailed accident investigation is preceded by a significant amount of routine work on searching and careful perusal of police files. Such a situation, on the one hand, deters the conduct of many studies; conversely, the process mostly repeats the work already performed by the police accident examiners.

A feasible solution that can greatly alleviate the situation is to have a computerized accident report containing the vocabulary used by the police investigators, and varying in accordance with the accident type under consideration. Such a tool, on the one hand, can assist the police examiner in the rapid registration of an occurrence; conversely, it would

result in the creation of one multi-aspect information source suitable for safety remedial work. In order to provide the proper information for the tool discussed, a comprehensive accident classification must be developed. Analyzing the Ayalon Highway accidents, we aspired to make the best contribution to the information base mentioned above. The approach used for the accident analysis was intentionally general; applied previously for single-vehicle accident classification (Gitelman & Hakkert, 1996). Its main points are:

- to reconstruct the accident occurrence, all the available information sources, i.e., on-site accident report, the police investigator's conclusions, motorists' evidence, and the judgement, are thoroughly scanned;
- comparing the sample examples, the set of descriptive items that are sufficient to reflect the accident contents, is defined;
- the set introduced above comprises the framework for a computer-fitted description of any accident considered, which is converted later into a database file;
- having the uniform set of database records, different accident characteristics are analyzed, with emphasis on accident mechanism exposure.

ACCIDENT DATA FOR ANALYSIS

The data pertaining to Ayalon motorway accidents were collected from the original police files which are kept in the Tel-Aviv police archives. As it was important to analyze the latest Ayalon accidents, all attainable 1995 files were taken into account, with the addition of accidents occurring during the second half of 1994. The total sample comprised 139 cases. The accident locations were repeatedly verified according to the parties involved and detailed map data.

The structure of the database file for Ayalon accident description is presented in Table 1. This framework is sufficient to keep both the formal accident data (day, time, location, severity), and the details of occurrence: for every vehicle involved, up to three manoeuvres prior-to-the-collision can be noted, in accordance with the manoeuvres of others (see fields A0-A2, B0-B2, C0-C2 in Table 1). The fields REASONS, NOTES, VISIBILITY, ROADCOND are intended to reflect specific factors and circumstances which are relevant to the case, e.g., "traffic jam," "roadworks," "wet road," "limited visibility," etc.

CONSIDERATION OF ACCIDENT CHARACTERISTICS

As detailed accident descriptions are presented in the database file, various types of in-depth analysis can be performed. For the urban motorway accidents considered, the following aspects were examined: accident location (along the motorway and with reference to interchange components); accident patterns; accident severity, and factors characteristic for the sample. All types of consideration were aimed to ascertain as many accident regularities as possible, and to expose accident mechanisms relevant for the group analyzed.

ACCIDENT LOCATIONS

The accident locations along the Ayalon motorway (Figure 1), demonstrate that the three southern interchanges and junctions between them are characterized by an increased number of accidents. While the whole road has an approximately equal accident distribution in the two directions: 52.5% to the north versus 47.5% to the south (the travelling directions are separated by railway tracks), the sites with more accidents tend to have them more to the south, whereas the remainder of sites are to the north (the difference is significant, $\alpha = 0.05$).

In order to identify the accident patterns relevant to different road structures within the motorway considered, the accident locations were classified with reference to interchange components (Figure 2):

ON - accidents that occur on the interchange, including the final part of exit ramps and the beginning of lane drops from the interchange leading to the on-ramp;
UNDER - accidents that occur under the bridge;
EXIT - accidents that occur at the exit ramp area, starting with the deceleration lane;
ENTR - accidents that occur at the entry ramp area;
BTW - accidents that occur at junctions between interchanges, i.e., accidents not belonging to any of the above locations.

Table 2 presents the accident distribution in accordance with their location and type of collision. It can be concluded from Table 2 that the share of accidents occurring at the interchange area (ON, UNDER, EXIT, ENTR) is about the same as between the interchanges: 52% versus 48%; and the majority of interchange-area accidents (69%) have EXIT and ON locations (whereas about half --46% -- of ON accidents occur at the top of exit ramps). The leading collision type everywhere is "rear-end" (50% of cases, on average); other dominant collision types are "side-side" (UNDER), "rear-side" (ON), "rear-side" (EXIT), and single-vehicle accidents (BTW).

ACCIDENT PATTERNS

In order to decide how to treat the phenomenon, it is first necessary to learn its mechanism. Therefore, it was of principal importance to point out accident patterns (mainly, vehicle manoeuvres prior to a collision) which characterize the Ayalon Highway accidents. With this in mind, the accident stories at five areas defined above were considered in detail. For example, the 26 EXIT area accidents included 6 cases with direct gore area involvement (i.e., one of the prior-to-a-collision manoeuvres was a gore area crossing); 15 cases with exit ramp involvement (i.e., one or both the vehicles were leaving or entering exit ramps while the accident occurred); 5 cases took place in the mainstream. Table 3 summarizes this consideration in general and demonstrates that accident pattern distribution changes insignificantly from area to area ($\chi^2_{16} = 24.19$). The most widespread patterns are:

- Vehicles, being in the same lane, do not keep a distance and collide "rear-end" (36.7% of all the cases, 27% in EXIT area);

- An accident occurs while one of the vehicles is changing lane (21.6% of the whole sample; 35.6% of EXIT accidents).

The full list of accident patterns for the Ayalon motorway during the period considered includes:

A- a late-coming attempt to exit the motorway (with sharp right-manoeuvre, crossing gore-area), 6 cases;
B- a late-coming attempt to return to or an early-coming attempt to enter the motorway (with sharp left-manoeuvre through the gore-area), 2 cases;
C- a single-vehicle accident (loss of control), 21 cases;
D- a deviation from a carriageway without intending to change a lane, 22 cases;
E- one vehicle collides with another while they are moving in a platoon, 51 cases;
F- a collision while changing a lane, 22 cases;
G- a pedestrian crossing the vehicle carriageway, 3 cases;
H- an opened door hits a motorcycle, 2 cases;
I- a collision at a junction with traffic lights (ON-area), the vehicles coming from different directions, 6 cases;
J- a passenger falling when a vehicle is in motion after stopping on a shoulder; 1 case;
K- a load falling from a moving vehicle, and hitting the following vehicle, 3 cases.

In order to select patterns that merit treatment as characteristic, an approach proposed by Heydecker & Wu (1991) was applied. They developed a technique for the identification of a typical subset feature when the common behaviour of the feature in the whole set is known. In a simplified version, one can manipulate the frequency of the feature in the subset and the evaluated median for the entire set. If the first value exceeds the second, the feature is considered to be specific for the subset discussed. Having used the number of cases for the accident patterns of Ayalon Highway as a feature considered, the median value for the whole sample was derived: it lies between 3 and 6, closer to 3. Consequently, from the above eleven accident patterns, six (A, C, D, E, F, I) were found to be characteristic for the urban motorway considered.

ACCIDENT SEVERITY

The severity rate of Ayalon motorway accidents is very low: there is only one fatal accident (single-vehicle) in the whole set, which occurred between the interchanges; 92% of the accidents are with slight injuries. In this regard, no difference was found between the areas ($\chi^2_8 = 3.55$) and between the collision types ($\chi^2_6 = 10.93$). However, the share of accidents with a high number of injuries (3+) is above the average in ON and EXIT areas. A higher number of injuries was observed in "rear-end" accidents in comparison with other types of collision: 25.7% with two injuries (the average is 20.9%), 22.8% with three or more (the average is 14.4%). This difference is confirmed statistically ($\alpha = 0.05$) and quite anticipated because one third (34%) of "rear-end" accidents are "chain"- accidents (more than two vehicles involved).

TRAFFIC FACTORS

Two factors were found to be characteristic for the Ayalon Highway accidents: "roadworks" and "traffic jams." While the "roadworks" factor appears uniformly through all the areas (8.6% of the cases), the "traffic jam" influence changes from area to area: 11% involvement in ON and ENTR accidents; 36% involvement in the remaining areas ($\alpha > 0.30$). The strongest influence of the "traffic jam" factor was observed in the EXIT area: in about half (46%) of the accidents, the vehicles moved in a jam.

The majority of accidents with "traffic jam" factor were of "rear-end" (71%) or "rear-side" (27%) type.

AN EXAMPLE: THE POTENTIAL FOR BOLLARD APPLICATION AT EXIT AREAS

Bollards are plastic post delineators which emphasize the gore area location at motorway exits (Hakkert & Gitelman, 1997). The tools are called to contribute to better arrangement of the traffic streams at motorway exit points, and reduce erratic vehicle manoeuvres at these areas. According to the purpose defined, the following summary of the Ayalon accidents promises a potential benefit of bollard application at the motorway gore areas:

- The erratic manoeuvre of exit gore area crossing appears in six accidents (23% of EXIT area cases; 4.3% of the whole set);

- The erratic manoeuvre of gore area crossing through all the interchange areas (EXIT, ENTR, ON) appears in nine cases - 6.5% of the whole set;

- The direct and indirect influence of the gore area, i.e., the situation where gore area emphasizing could help to avoid an erratic manoeuvre, is relevant to fifteen accidents (10.8% of the cases, including all the areas considered).

CONCLUSIONS

In this study, we sought to perform an in-depth consideration of accidents occurring on the Ayalon Highway -- an urban motorway in Israel. Based on a sample of 139 most recent accidents, the motorway accident location and severity profiles were analyzed, and the dominant accident patterns, including collision types, vehicle manoeuvres prior-to-a-collision, and factors essential for the occurrences, were pointed out.

The method of data presentation (in particular, the developed computer-fitted form of accident description) and analysis was aimed to provide the best contribution to a comprehensive accident classification -- the information basis of computerized accident reporting. The latter presents a tool that is needed, on the one hand, to facilitate the regular work on accident registration performed by the police, and, conversely, to provide a satisfactory background for various crash investigations.

The results helped to reach a conclusion concerning the potential efficiency of bollard application at exit gore areas of the Ayalon motorway. Combining the results of accident analysis with experimental field observations and literature review, the bollard treatment was finally recommended for application on the Ayalon Highway (Hakkert & Gitelman, 1997).

A large proportion of accidents analyzed occurred between interchanges where a part of them are single-vehicle accidents; another includes rear-end collisions, and a third involves lane-changes. The Ayalon Highway Authority is in the process of installing a real-time traffic control and surveillance system. This will include real-time traffic monitoring and communication with drivers through Lane Control Signs and Variable Message Signs. It is believed that such interaction can be utilized to reduce the number of accidents of the types mentioned above.

REFERENCES

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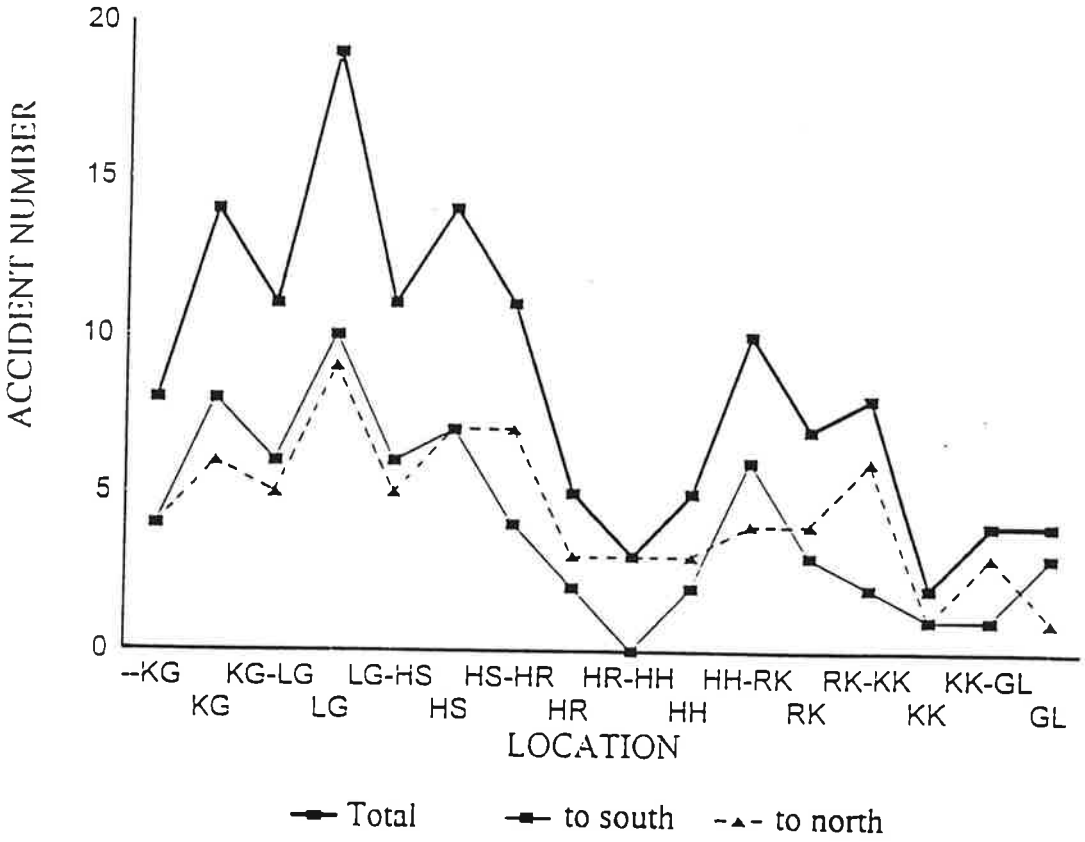

Interchanges: KG - Kibutz Galuiot; LG - Lagardia; HS - Hashalom; HR - Harakevet; HH - Hahalaha; RK - Rokach; KK - Keren Hakayemet; GL - Glilot; the remainder of locations are intermediate junctions.

Figure 1. Ayalon Accident Location along the Motorway: Grouped for Interchanges and Intermediate Junctions.

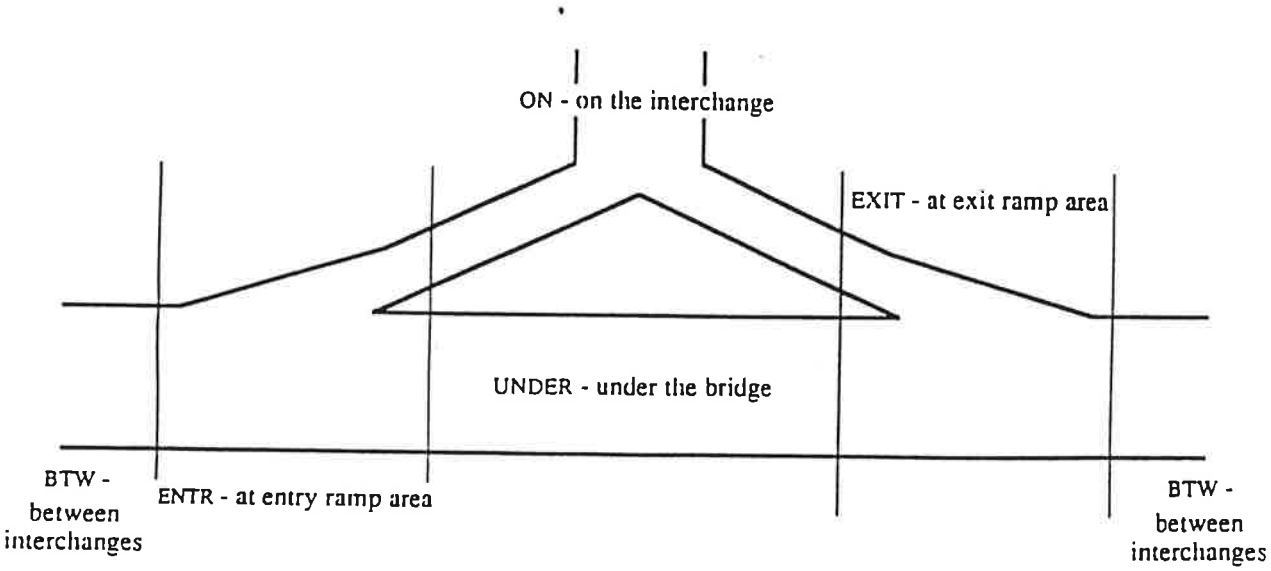

Figure 2. Motorway Accident Location with Reference to Interchange Components.

Table 1. Database File Structure For Ayalon Motorway Accident Description

Field Name	Description	Characteristics	Example* *(comments)*
POLICE FILE	Police file number	Original	4622
DATE	Accident date	Original	17.07
YEAR	Accident year	95 or 94	95
HOUR	Accident hour	Original	23:00
DIRECTION	Travelling direction	North or South	N *(north)*
INTERCHANGE	Interchange name	One of eight	KK *(Keren Hakayemet)*
LOCATION	Accident location	Before/After interchange; Exit ramp; Gore area; etc.	Gore Area, ER to ICh *(gore area & exit ramp involved)*
VEHNUMBER	Number of vehicles involved	1, 2, 3+	2
ACCTYPE	Accident type	Rear-end/ Rear-side/ Multiple rear-end/ etc.	Rear-end? *(apparently, rear-end type)*
A-VEHICLE	Type of vehicle **A**	Private/ Light goods/ Truck/ Motorcycle	Pr *(private)*
B-VEHICLE	Type of vehicle **B**	See above	Pr *(private)*
C-VEHICLE	Type of vehicle **C**	See above	--
A0 A1 A2	Manoeuvres of vehicle **A**	Chain of vehicle movements prior to the collision, by short sentences	right lane dev.right, crossed gore area hit **B**
B0 B1 B2	Manoeuvres of vehicle **B**	See above	ER, before **A** ER, left lane was hit by **A** behind
C0 C1 C2	Manoeuvres of vehicle **C**	See above	-- -- --
REASONS	Reasons for the manoeuvres performed	Incl. traffic conditions & drives' explanations, according to manoeuvres, by short sentences	**A1**-late to turn right; **A2**:"B was stopping" *("" mean driver's version)*
NOTES	Remarks about the occurrence & drivers involved	Incl. general road or traffic conditions & previous offenses of guilty party	**A** has 24 prevoffenses in 1969-1992
LANES	Number of lanes	2,3,4 (from the police file)	3
VISIBILITY	Visibility conditions	If a deficiency is noticed in the police file, e.g., night-lit, lighting failed,etc.	--
ROADCOND	Road conditions	If special weather or road conditions are noticed, e.g., wet, slippery, left curve, etc.	--
KILLED	Number of fatalities	A number	0
SERINJ	Number of serious injuries	A number	0
SLINJ	Number of slight injuries	A number	2
TO_BLAME	Guilty party	According to judgement	**A**-sigh violation

*The case: Vehicle **A** was on the right lane of the motorway, before the exit to KK-interchange, when it sharply deviated right to the exit through the gore area, and hit from behind vehicle **B** that was going on the left lane of exit ramps up to the interchange.

Table 2. Ayalon Motorway Accident Distribution in Accordance with Their Location and Type of Collision

Accident Location with Reference to Interchange	Type of Collision						Total
	Single-Vehicle Accident	Side-Side	Rear-Side	Rear-End	With a Pedestrian	With Load Dropped	
UNDER	2	4 40%	--	4 40%	--	--	10 *14%[a]*
ON	1	1	9 37%	13 54%	--	--	24 *33.8%[a]*
EXIT	5	1	9 36%	9 36%	1	--	25 *35.2%[a]*
ENTR	1	1	2	8 67%	--	--	12 *17%[a]*
BTW	13	9	5	35 52%	2	3	67
Total	22 17.4%	16	25 18.1%	69 50%	3	3	138

[a]Division of interchange-area accidents.
The rest of percentages illustrate the dominant collision types for specific locations.

Table 3. Ayalon Motorway Accident Distribution According to Accident Location and Vehicles' Manoeuvres Prior-to-a-Collision

Accident Location with Reference to Interchange	Vehicles' Manoeuvres Prior-to-a-Collision					Total
	Single Vehicle, Loss of Control	Two Vehicles Moving the Same Direction			Others[a]	
		Changing a Lane	Parallel Lanes, Non-Intended Deviation	The Same Lane, Not Keeping Distance		
UNDER	1	1	3	4	1	10
ON	1	2	2	13	6	24
EXIT	5	9	4	7	1	26
ENTR	1	5	2	4	--	12
BTW	13	13	13	23	5	67
Total	21	30	24	51	13	139

[a] Others: with a pedestrian; a passenger falling from the vehicle; a load falling from the vehicle; joining on-interchange traffic flows.